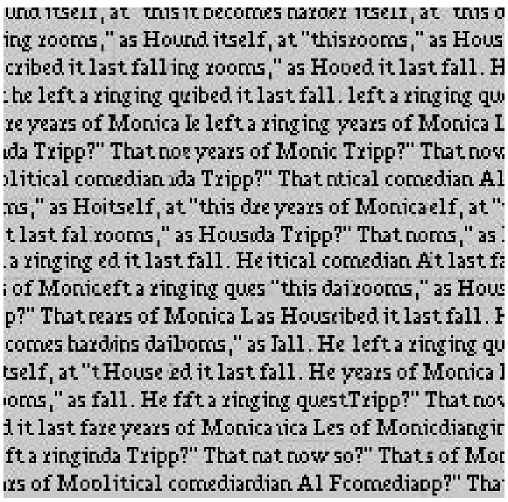
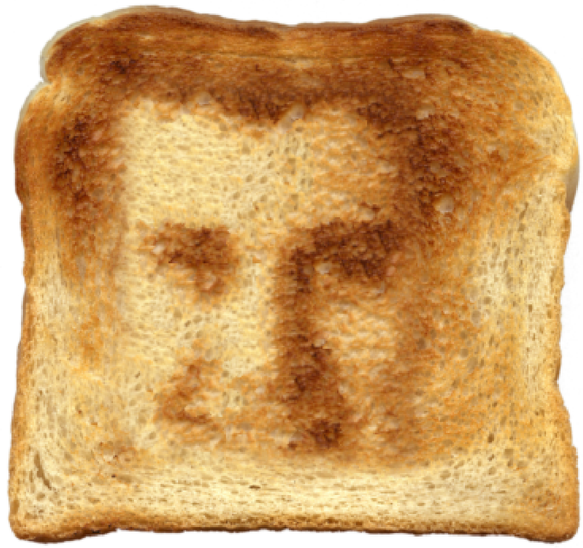
Programming Project #2: Image Quilting
CS445: Computational Photography





Due Date: 11:59pm on Tuesday, Oct. 1st, 2019

Starter code

Overview

The goal of this assignment is to implement the image quilting algorithm for texture synthesis and transfer, described in this SIGGRAPH 2001 paper by Efros and Freeman. Texture synthesis is the creation of a larger texture image from a small sample. Texture transfer is giving an object the appearance of having the same texture as a sample while preserving its basic shape (see the face on toast image above). For texture synthesis, the main idea is to sample patches and lay them down in overlapping patterns, such that the overlapping regions are similar. The overlapping regions may not match exactly, which will result in noticeable edges. To fix this, you will compute a path along pixels with similar intensities through the overlapping region and use it to select which overlapping patch from which to draw each pixel. Texture transfer is achieved by encouraging sampled patches to have similar appearance to a given target image, as well as matching overlapping regions of already sampled patches. In this project, you will apply important techniques such as template matching, finding seams, and masking. These techniques are also useful for image stitching, image completion, image retargeting, and blending.

Here, I have included some sample textures to get you started (these images are taken from the paper). You will implement the project in several steps.

Randomly Sampled Texture (10 pts)

Create a function `quilt_random(sample, out_size, patch_size)` that randomly samples square patches of size `patch_size` from a `sample` in order to create an output image of size `out_size`. Start from the upper-left corner, and tile samples until the image are full. If the patches don't fit evenly into the output image, you can leave black borders at the edges. This is the simplest but least effective method. Save a result from a sample image to compare to the next two methods.

Overlapping Patches (30 pts)

Create a function `quilt_simple(sample, out_size, patch_size, overlap, tol)` that randomly samples square patches of size `patch_size` from a `sample` in order to create an output image of size `out_size`. Start by sampling a random patch for the upper-left corner. Then sample new patches to overlap with existing ones. For example, the second patch along the top row will overlap by `patch_size` pixels in the vertical direction and `overlap` pixels in the horizontal direction. Patches in the first column will overlap by `patch_size` pixels in the horizontal direction and `overlap` pixels in the vertical direction. Other patches will have two overlapping regions (on the top and left) which should both be taken into account. Once the cost of each patch has been computed, randomly choose on patch whose cost is less than a threshold determined by `tol` (see description of `choose_sample` below).

I suggest that you create two helper functions `ssd_patch` and `choose_sample`. `ssd_patch` performs template matching with the overlapping region, computing the cost of sampling each patch, based on the sum of squared differences (SSD) of the overlapping regions of the existing and sampled patch. I suggest using a masked template. The template is the patch in the current output image that is to be filled in (many pixel values will be 0 because they are not filled in yet). The mask has the same size as the patch template and has values of 1 in the overlapping region and values of 0 elsewhere. The SSD of the masked template with the input texture image can be computed efficiently using filtering operations (see tips section down below), producing an image in which the output is the overlap cost (SSD) of choosing a sample centered at each pixel.

`choose_sample` should take as input a cost image (each pixel's value is the cost of selecting the patch centered at that pixel) and select a randomly sampled patch with low cost, as described in the paper. One way to do this is to first find the minimum cost `minc` and then to sample a patch within a percentage of that value:
`row, col = np.where(cost < minc*(1+tol))` . If the minimum is approximately zero (which can happen initially), it might make sense to set `minc` to a larger value, e.g., `minc=max(minc,small_cost_value);`. Another way is to sample one of the K lowest-cost patches.

After a patch is sampled, its pixels should be copied directly into the corresponding position in the output image. Note that it is very easy to make alignment mistakes when computing the cost of each patch, sampling a low-cost patch, and copying the patch from the source to the output. Use an odd value for `patch_size` so that its center is well-defined. Be sure to thoroughly debug, for example, by checking that the overlapping portion of the copied pixels has the same SSD as the originally computed cost. As a sanity check, try generating a small texture image with low tolerance (e.g., 0.00001), with the first patch sampled from the upper-left of the source image. This should produce a partial copy of the source image. Once you have this function working, save a result (with higher tolerance for more stochastic texture) generated from the same sample as used for the random method.

Seam Finding (20 pts)

Next, incorporate seam finding to remove edge artifacts from the overlapping patches (section 2.1 of the paper):

1. Use the cut function in utils.py (download starter_codes at the top), or, if you want a challenge and 10 bonus points, create your own function `cut(bndcost)` that finds the min-cost contiguous path from the left to right side of the patch according to the cost indicated by `bndcost`. The cost of a path through each pixel is the square differences (summed over RGB for color images) of the output image and the newly sampled patch. Use dynamic programming to find the min-cost path. Use this path to define a binary mask that specifies which pixels to copy from the newly

sampled patch. Note that if a patch has top and left overlaps, you will need to compute two seams, and the mask can be defined as the intersection of the masks for each seam (`mask1&mask2`). To find a vertical path, you can apply `cut` to the transposed patch, e.g., `cut(bndcost.T).T`. If you do use the included function, take the time to understand it.

2. Create a function `quilt_cut` that incorporates the seam finding and use it to create a result to compare to the previous two methods.

Texture Transfer (30 pts)

Your final task is to create a function `texture_transfer`, based on your `quilt_cut` function for creating a texture sample that is guided by a pair of sample/target correspondence images (section 3 of the paper). You do not need to implement the iterative method described in the paper (you can do so for extra points: see Bells and Whistles). The main difference between this function and `quilt_cut` is that there is an additional cost term based on the difference between the sampled source patch and the target patch at the location to be filled.

Bells & Whistles

- (**10 pts**) Create and use your own version of `cut` function. To get these points, you should create your own implementation without basing it directly on the provided function (you're on the honor code for this one).
- (**15 pts**) Implement the iterative texture transfer method described in the paper. Compare to the non-iterative method for two examples.
- (up to **20 pts**) Use a combination of texture transfer and blending to create a face-in-toast image like the one on top. To get full points, you must use some type of blending, such as feathering or Laplacian pyramid blending.
- (up to **40 pts**) Extend your method to fill holes of arbitrary shape for image completion. In this case, patches are drawn from other parts of the target image. For the full 40 pts, you should implement a smart priority function (e.g., similar to Criminisi et al.).

Deliverables

Submission is similar to project 1: create a web page and thumbnail and submit code/text/link on Compass. See project instructions for details. Remember to specify how many points you think you should get (and for what) in your Compass submission.

Use words and images to show what you've done. Please:

- Compare random, overlapping, and seam-finding methods for one texture sample (similar to Figure 2 of the paper, but with a different texture).
- Create an illustration of the seam finding. Include three images: the two overlapping patches and the cost (squared difference). On top of the cost image, plot the min-cost path. You can edit `cut` function in utils.py to create this display or to output the path to display.
- Using the above figures as illustrations, briefly explain the image quilting texture synthesis method. Show 4 more results, including at least two from your own images.
- Show at least two results for texture transfer, including at least one result that uses your own images (either for the target or source texture or both). Briefly explain (one or two sentences is fine) how the texture transfer works.

- In your explanations, be sure to include any special design decisions or difficulties that you encounter.
- Describe and bells and whistles under a separate heading.

Scoring

The core assignment is worth **100** points, as follows:

- **10 points** for the random patch texture synthesis with one result.
- **30 points** for the overlapping patch texture synthesis with one result.
- **20 points** for the seam finding texture synthesis with five results (including at least two from your own images).
- **30 points** for texture transfer with at least two results (including at least one from your own images).
- **10 points** for quality of results (e.g., 0=poor 5=average 10=great 15=amazing)

You can also earn up to **85 extra points** for the bells & whistles mentioned above. To get full points, you must implement the method, show the requisite results, and explain and display results clearly.

Tips

- Useful Python functions: `cv2.filter2D`, `matplotlib.pyplot.plot`, `numpy.where`, `numpy.ndarray.sum()`, `numpy.square`
- Initially, don't worry about speed! Choose a small output size and get it working first.
- For efficiency, use filtering to compute SSD. Note that part of the computation only needs to be done once (not for each patch), so that can be cached. Suppose I have a template `T`, a mask `M`, and an image `I`: then, `ssd = ((M*T)**2).sum() - 2 * cv2.filter2D(I, ddepth=-1, kernel = M*T) + cv2.filter2D(I ** 2, ddepth=-1, kernel=M)`
- Remember, using or even looking at outside code is not allowed!